

BNL Workshop

Comments on CF₄-based operations, and GEM-based photodetectors.

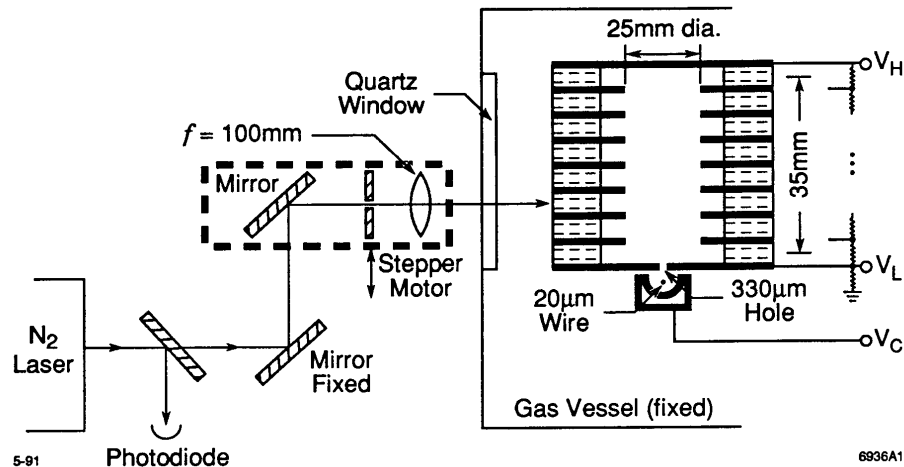
J. Va'vra, SLAC

In this talk I will comment on:

- . CF_4 purity problems
- . Aging in CF_4 -based gases:
 - a) aging in CF_4 -only gas,
 - b) quenching in CF_4 -based gases,
 - c) Malter effect in CRID,
 - d) electrolytical effects in CsI
- . Experience with quadruple-GEM + pad detector
- . Things which would worry me if I have to build it.

Purity problems with CF₄-based gas operations

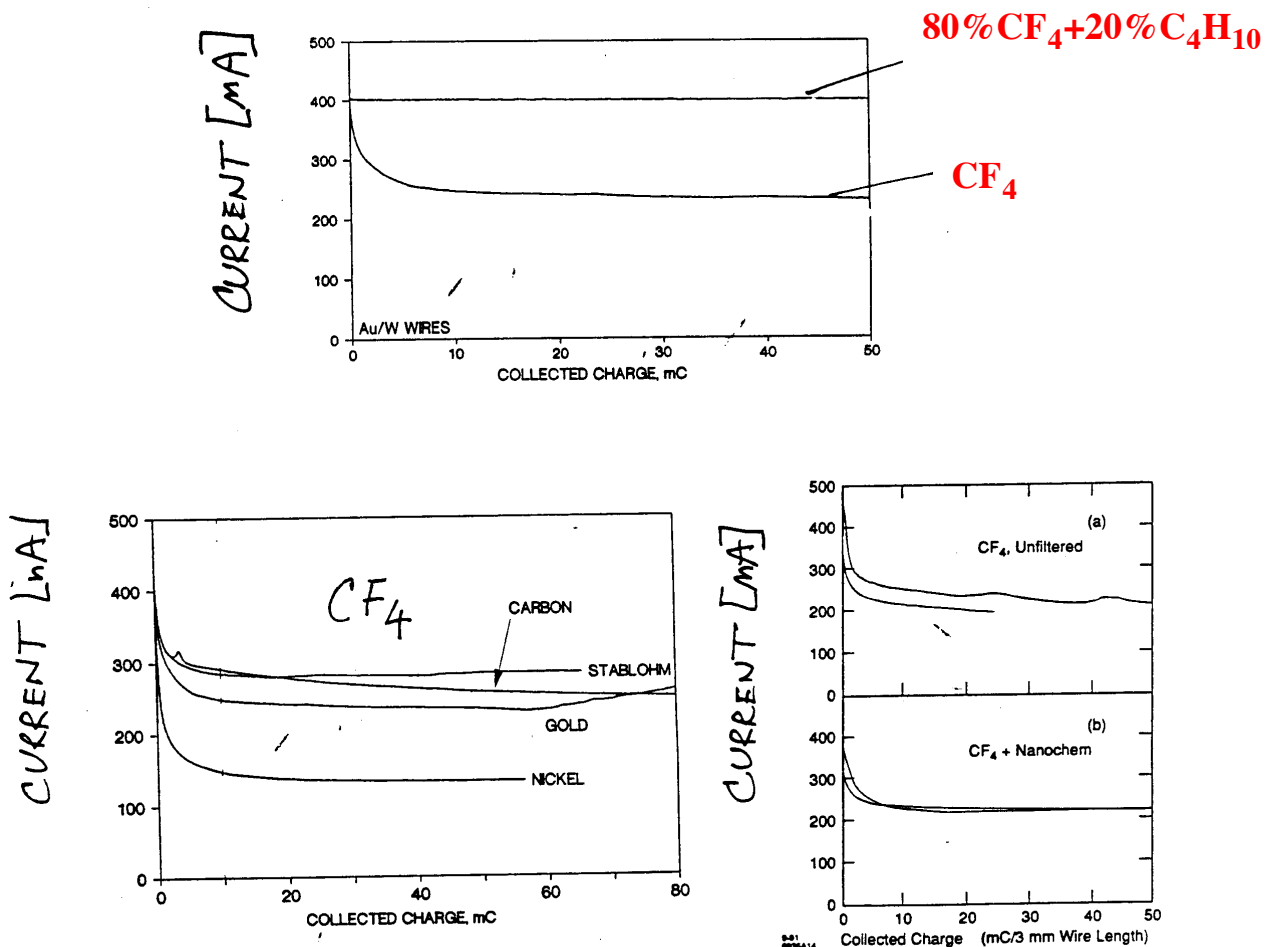
(J. Va'vra et al., NIM A324(1993)113, and NIM A370(1996)352)



- The system we had was very clean “TMAE” compatible (s.s. tubing, <1ppm O₂-level, etc.)
- CF₄ gas (99.7% purity) can be dirty. Could drift less than a cm. Usual filtering methods did not work (Oxisorb, 13X mol sieve).
- A solution:
 - a) Initially by adding a Nanochem Filter – a very expensive solution.
 - b) Finally solved by adding the Silica Gel and the Ridox filters (elemental copper).
(In addition to Oxisorb + 13X filters).

Wire aging in CF_4 gas

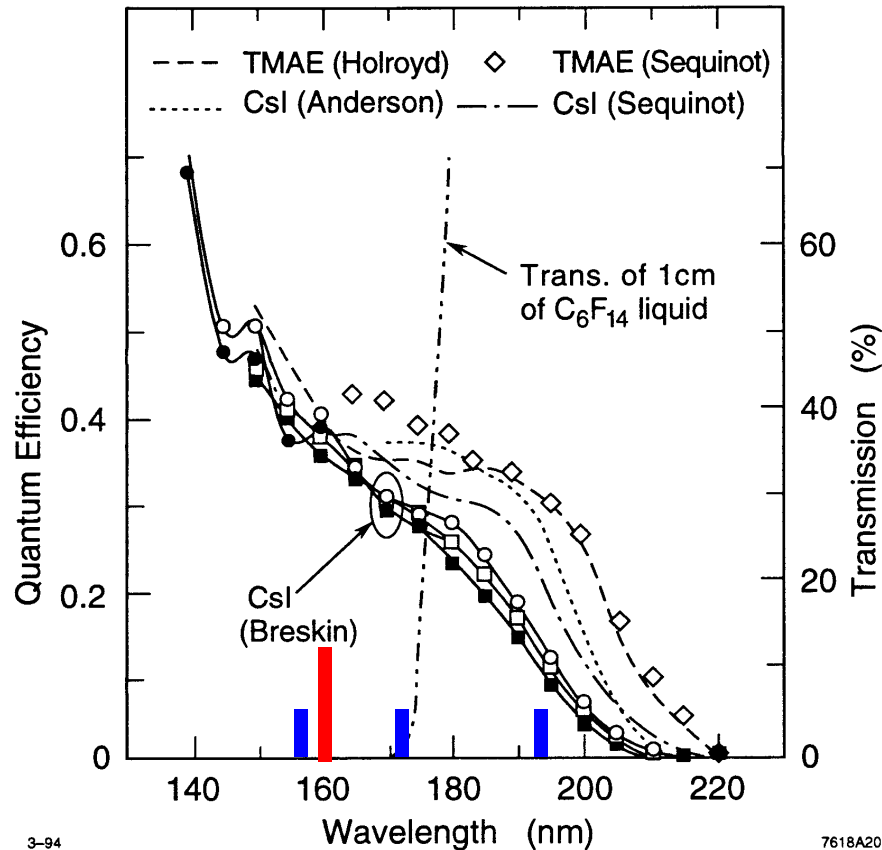
(J. Wise, Ph.D. Thesis)



- $80\% \text{CF}_4 + 20\% \text{C}_4\text{H}_{10}$ is not aging, CF_4 does !!!
- CF_4 alone is aging fast, probably caused by a formation of a nonconducting metal-fluoride. This may be significant from point of view of creating the resistive layer on the cathode and triggering of the Malter effect – see later.
- Nanochem filter did not help !!!

Q.E. of CsI and TMAE, & various emission lines produced in the avalanches by electron collisions

Reflective Q.E. measurements:



- $e^- + C \rightarrow C^* + \gamma$, $E_\gamma \sim 156, 166, 193$ nm
- $e^- + CF_4 \rightarrow (CF_3^+)^* \text{ or } (CF_4^+)^* \rightarrow \gamma$, $E_\gamma \sim 160$ nm

CF_4 gas scintillates in the UV region:

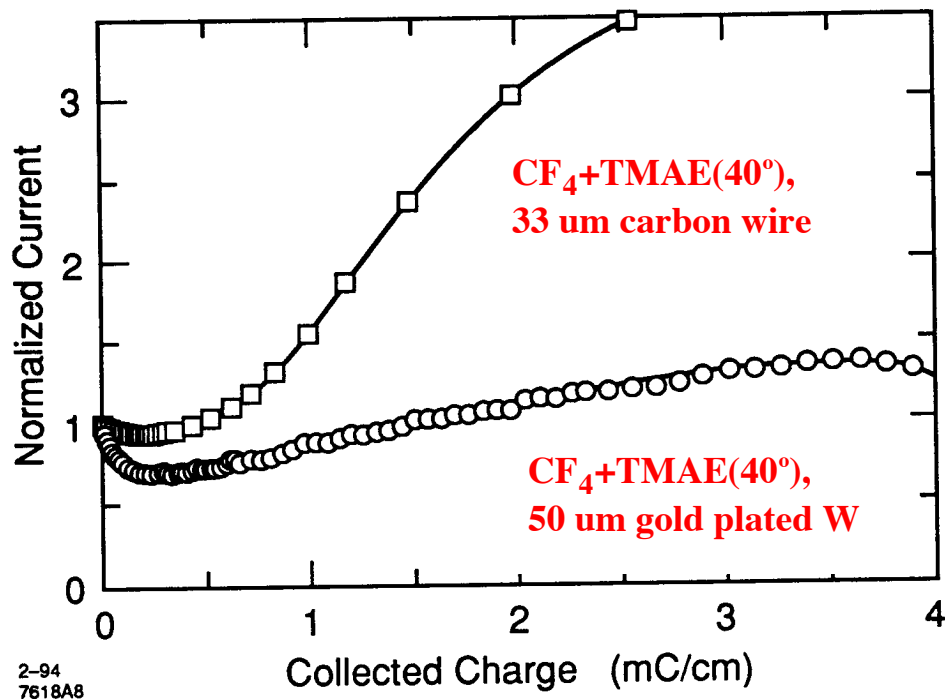
$$1200 \gamma / (\text{MeV} \cdot 4\pi) (150-500\text{nm}) \sim$$

16% of that of Xe !!!

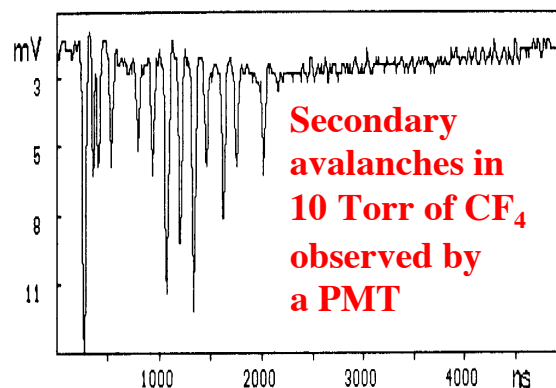
(A. Pansky et al., NIM A354(1995)262)

Wire aging process in CF_4 +TMAE is very “unusual”

(J. Va'vra et al., NIM A370(1996)352)



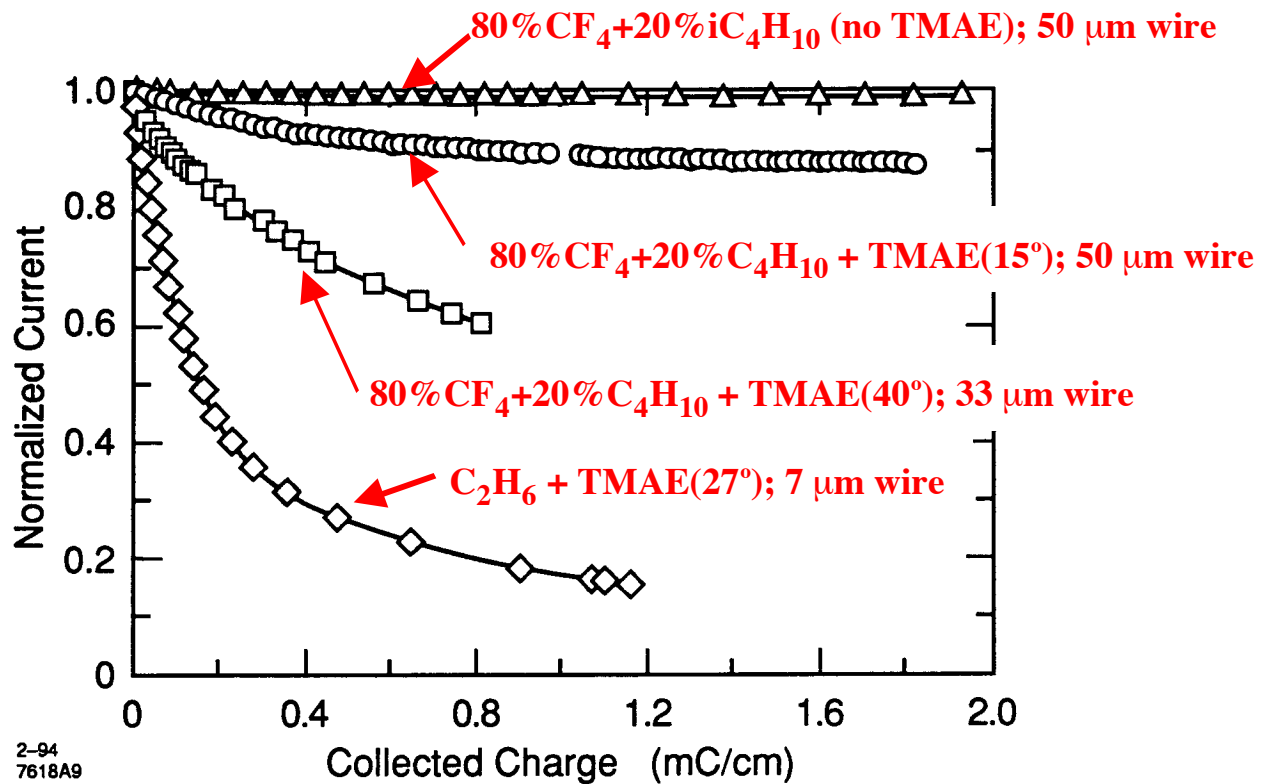
A. Pansky et al., NIM A354(1995)262:



- Increase in photocurrent is caused by the photo-emission of CF_4 and build up of photosensitive deposits on the cathode !!!

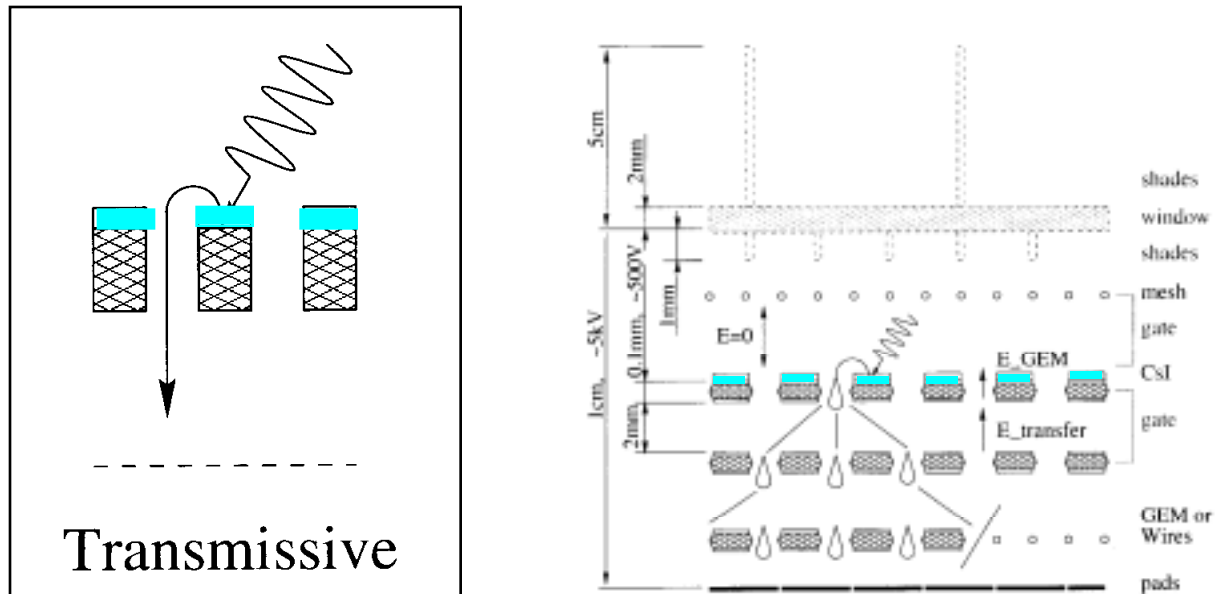
Addition of C_4H_{10} gas stops the photo-emission

(J. Va'vra et al., NIM A370(1996)352)

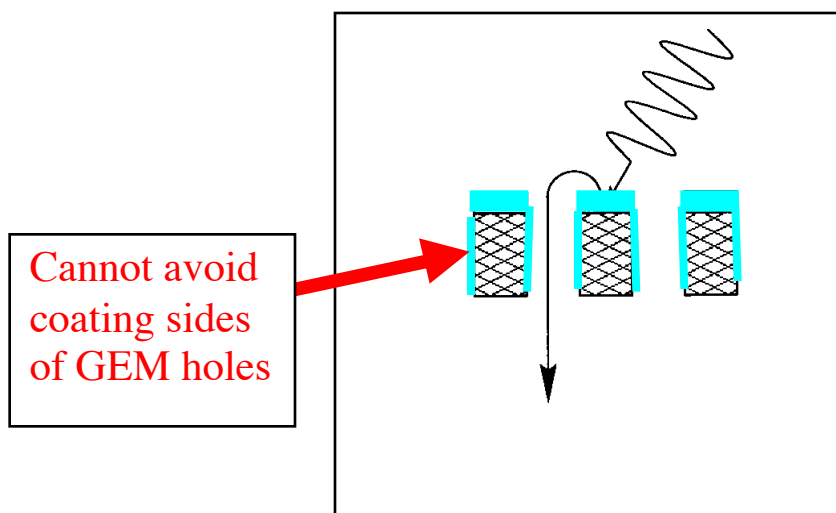


- Addition of iC_4H_{10} stops photo-emission and one gets a “normal aging behavior, i.e., current falls as a function of dose.”

PHENIX proposal - HBD detector with a CsI photocathode:

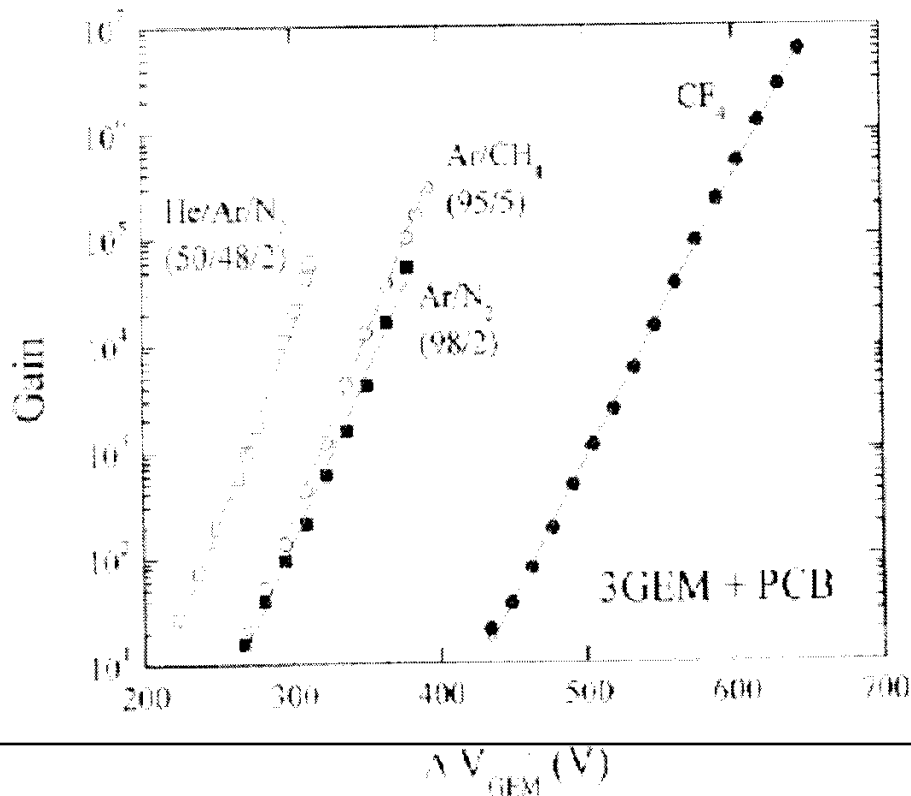


However, in reality might be as follows:



Therefore, CsI will be directly exposed to avalanche.
What could be the possible consequences ?

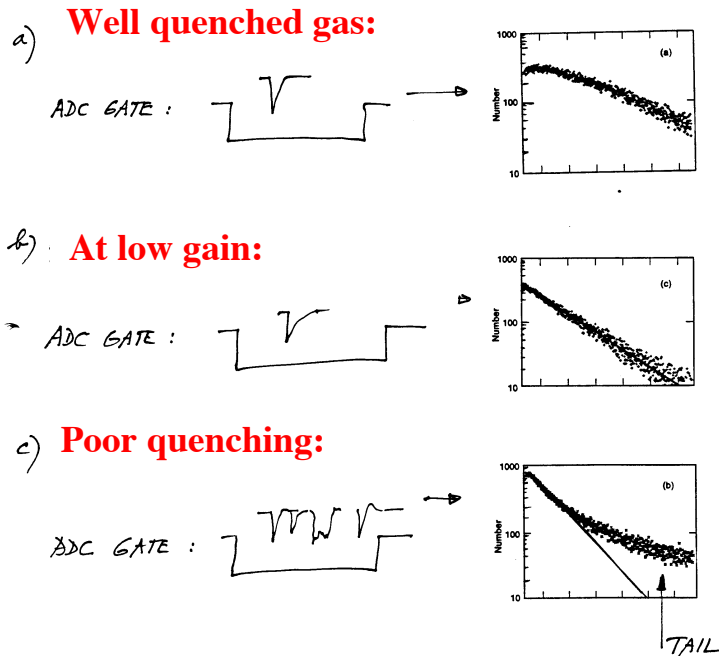
Apparently it is OK from point of view of achieving a higher gain (A. Breskin's group)



However, that may not be the entire story. One has to also look at the quenching behavior, and also at the electrolytic effects causing possibly the changes in the CsI resistance, and subsequently the Malter effect.

How to recognize the poor quenching in the single electron pulse height spectrum ?

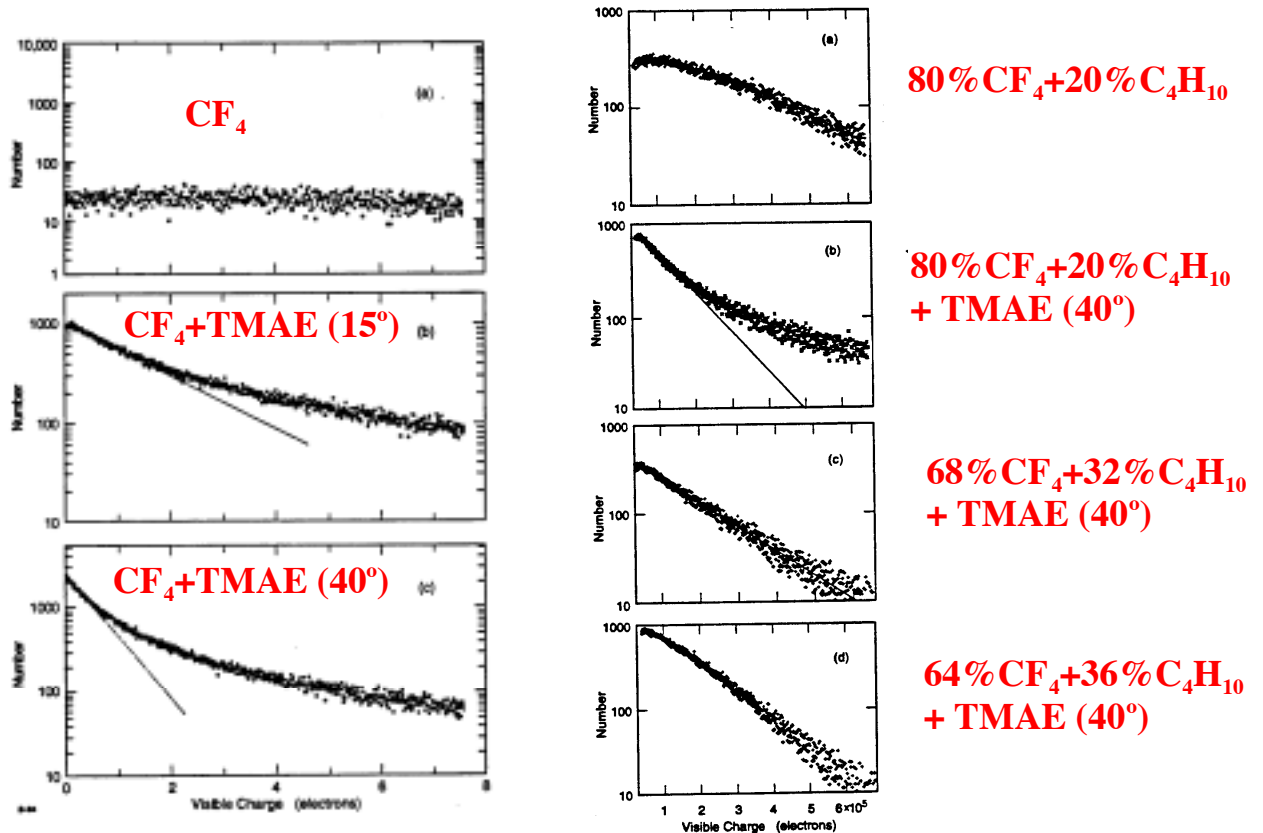
(J. Va'vra et al., NIM A370(1996)352)



A gas, such as CF_4 , is producing many avalanche photons, which in turn produce secondary electrons at the cathode, which in turn produce secondary avalanches causing an excessive tail in the single electron pulse height spectrum; this can be observed as gains approach 10^5 or more.

One needs to add a large amount of C_4H_{10} to stop the secondary effects in the CF_4 +TMAE mixture

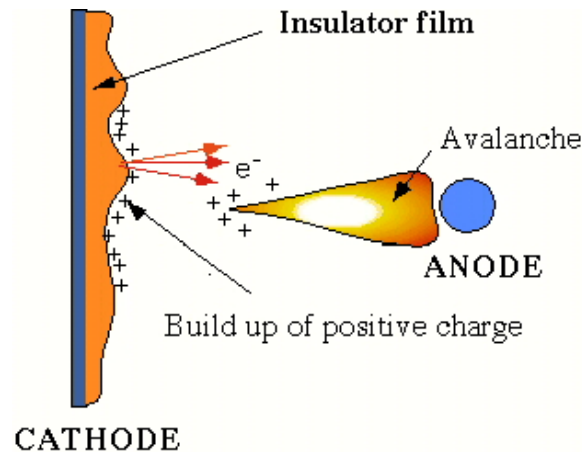
(J. Va'vra et al., NIM A370(1996)352)



The CF_4 single electron spectrum is very broad, probably because of the electron attachment in the avalanche at the electric field between ~ 5 - 35 kV/cm at 1 bar (J. Va'vra, NIM A323(1992)34). Addition of TMAE amplifies the cathode secondary effects caused by the photo-emission of CF_4 . Addition of C_4H_{10} helps to stop it. The CsI photocathode present in the GEM holes may cause similar secondary effects – needs to be checked.

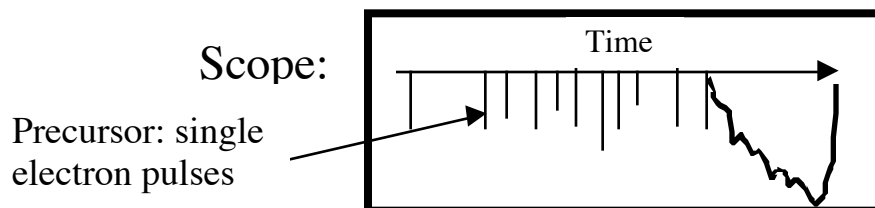
Secondary electron emission due to the Malter effect:

(L.Malter, Phys. Rev. 50(1936); and my talk at DESY Aging Workshop, 2001)



Necessary condition for electron emission:

- a) Localized primary ionization deposit.
- b) An insulator on the cathode.
- c) A rate of the charge build up is higher than its removal rate.
- d) Excessive field cathode gradients help to trigger it.
- e) **To start the effect, it needs an ignition.**



Signature:

The current starts as single electrons and can grow up to hundreds of nA. The effect is very localized. It is persistent even after the source of radiation is removed.

Why to worry about this at all ?

- Wojcicki's group at Stanford was preparing a straw tube-based experiment at BNL. The gas used was CF_4 -based mixture. One day, during the night, the gas run out, and the chamber ignited a Malter discharge. The trip setting was a way up ($\sim 10\mu\text{A}$), and next morning the inner copper conductor was gone, all etched away.
- Can one ignite something similar in the GEM-based or the μ -MEGAS-based chamber, especially if the sparking or the electrolytic currents are allowed ?

Methods to create the insulating film:

- a) Avalanche producing polymers.
- b) Glue on electrodes.
- c) Gas pollutants.
- d) Insulating deposits left from sparks.
- e) Corona on sharp point on the cathode.
- f) Allowing the Malter currents to go on undetected.
- g) Poor plating.
- h) Some oxides are highly resistive.
- i) Some photosensitive molecules (such as TMAE).
- j) Conducting epoxy is not conducting enough.
- k) Carbon composite materials may not be conducting enough (HERA-B experience with Pokalon-C).
- l) Etching a conducting layer away from the cathode.
- m) etc.

Ignition mechanisms:

- a) Highly ionizing heavy ions.
- b) Fe^{55} X-rays.
- c) Sparks.
- d) Sharp points on electrodes causing corona.
- e) Thin anode wires help the ignition.
- f) Background muons aligned with E of a TPC (CRID).

Relationship between the maximum rate capability and the cathode film resistivity.

- Consider a film on cathode with resistivity ρ_V , relative dielectric constant ϵ_r .
- Consider the time domain only (neglect gain variation).
- The time constant describing the neutralization of the positive charge is $RC \sim \epsilon_r \epsilon_0 \rho_V$.
- Assume the charge is deposited in one spot with a mean time period of T , i.e., with a rate of $r = 1/T$.
- To prevent the charge build up, one needs: $RC < 0.1 T$. Therefore, the maximum rate is:

$$r_{\max} \sim 1/(10 RC) = 1/(10 \epsilon_r \epsilon_0 \rho_V)$$

- For $\epsilon_r \sim 4$, $\epsilon_0 = 8.87 \text{ pF/m}$, $\rho_V \sim 2.8 \times 10^7 \text{ } \Omega\text{.cm}$:

$$r_{\max} \sim 10 \text{ kHz.}$$

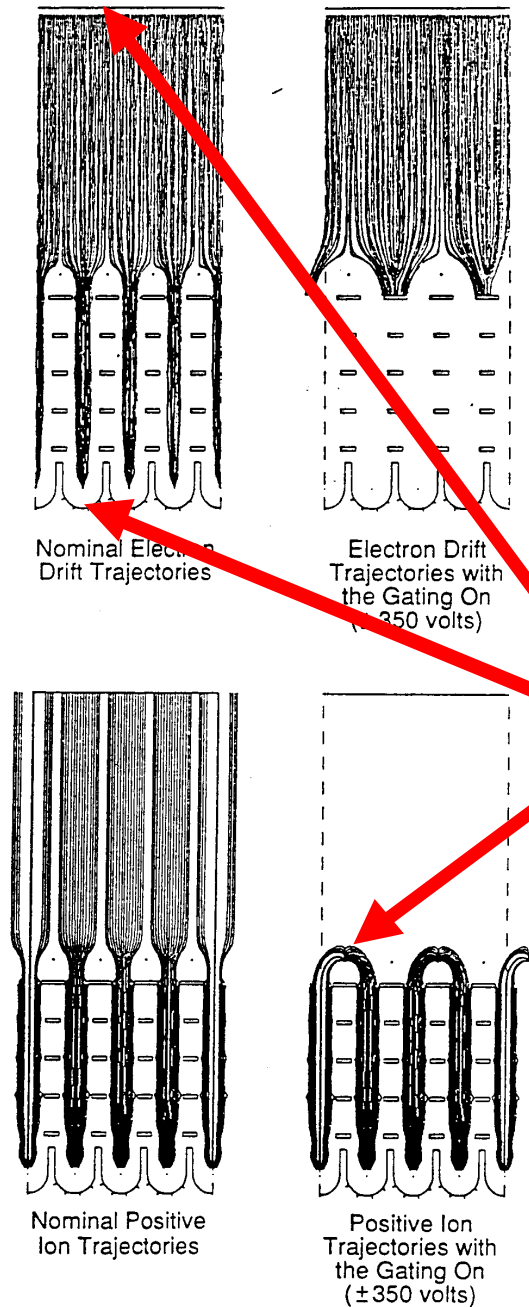
- For $\epsilon_r \sim 4$, $\epsilon_0 = 8.87 \text{ pF/m}$, $\rho_V \sim 2.8 \times 10^{12} \text{ } \Omega\text{.cm}$:

$$r_{\max} \sim 1 \text{ Hz.}$$

Examples of the Malter effect

- 1) The first imaging of this effect ever – CRID experience
(J. Va'vra, NIM A367(1995)353).
- 2) Subsequent lab tests (J. Va'vra, NIM A367(1995)353).
- 3) Attempts to ignite the Malter effect in a CsI-based chamber failed at the Weizmann Inst. – why ?

SLD CRID detectors did have the Malter currents under three different conditions (J. Va'vra, NIM A367(1995)353).



I have observed a Malter effect from all these three cases from:

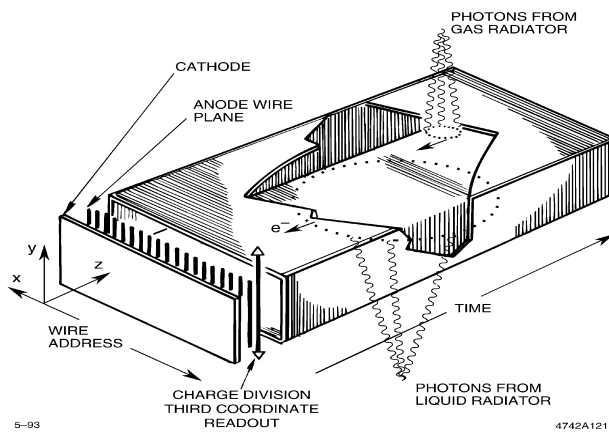
- a) a HV cathode
- b) a detector cathode
- c) a gating wire surface, while gating was on.

The first two cases were caused by an excessive rate of UV calibration fibers. Solved by a reduction of the UV fiber-firing rate. The third case was solved by not gating throughout the entire SLD experiment !!!.

Luckily, all this was observed during the early period of the SLD operation. Fortunately, we did not have these problems during the regular SLD data taking.

Examples of the Malter effect

- 1) The first imaging of this effect ever (J. Va'vra, NIM A367(1995)353).
(Tanks to excellent single electron imaging capability in CRID).



Discharging time constant:

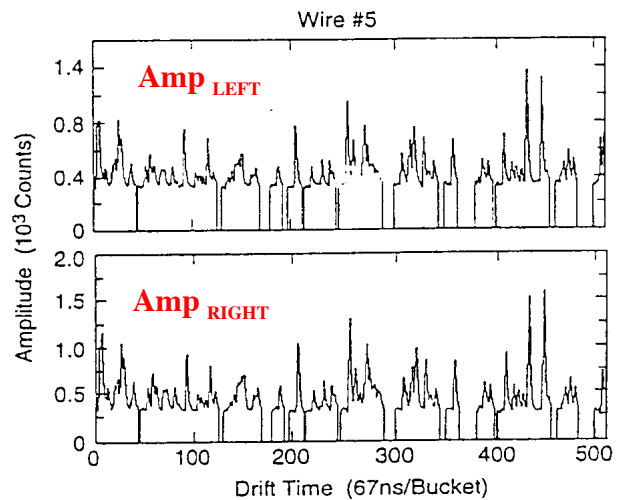
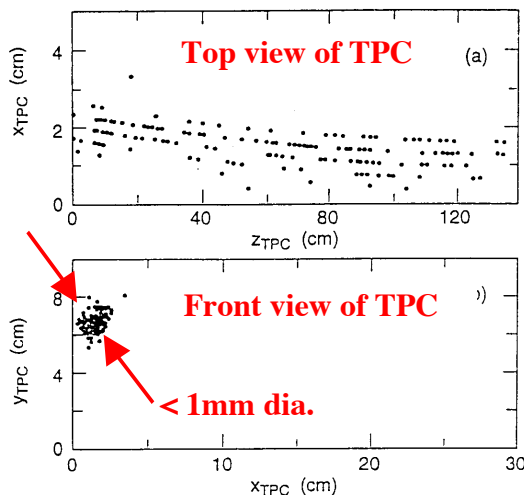
$$RC \sim \epsilon_r \epsilon_0 \rho_{\text{film}}$$

For:

$$\epsilon_r \sim 4, \epsilon_0 \sim 8.85 \text{ pF/m},$$

$$\rho_{\text{film}} \sim 10^{15} \Omega \text{ cm}$$

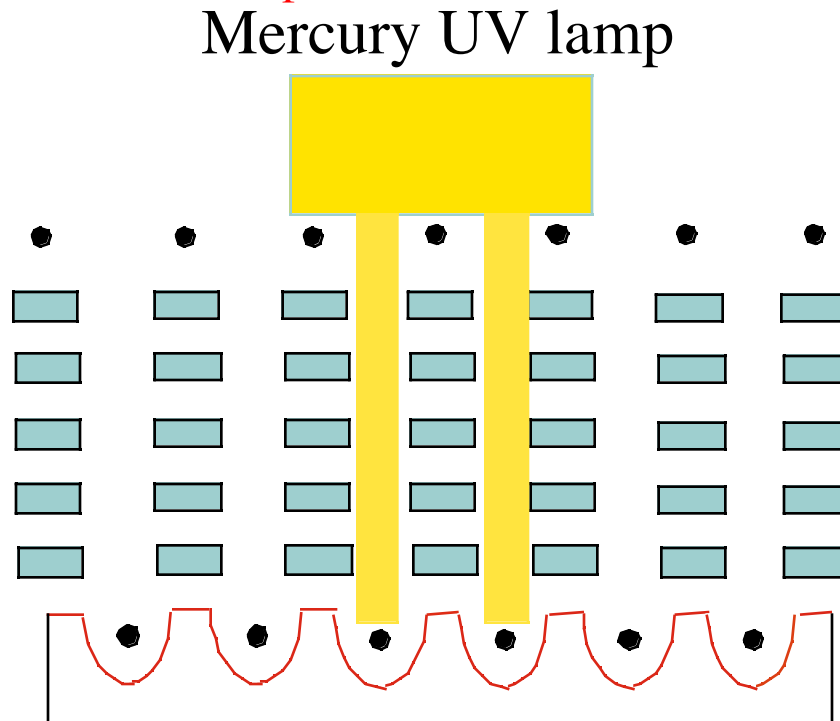
$$\Rightarrow RC \sim 15 \text{ min.}$$



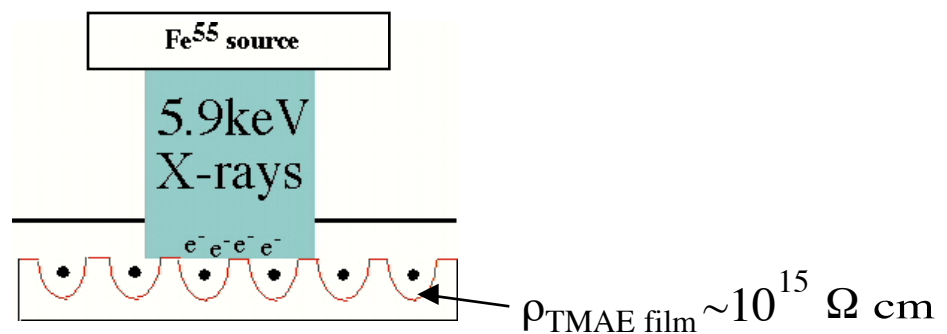
- Observed bursts of single electron pulses every 15 minutes in the location of UV fibers, which were used for calibration.
- The UV fibers were creating a continuous photo-electron rate of $\sim 10 \text{ Hz/cm}$ of wire length for ~ 2 years, which created conditions to trigger the Malter effect.
- Solved by a reduction of the UV fiber rate by $\sim 2000\times$.

2) It was very easy to excite the Malter effect in the CRID detectors in the lab, if they were previously been used in TMAE. (J.Va'vra et al., NIM A367(1995)353)

a) Either with a UV lamp:

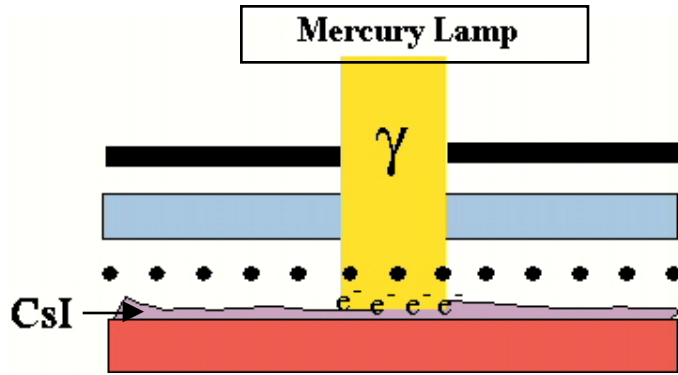


b) Or with an Fe^{55} source:



Answer: a) Resistivity of the “clean” TMAE film is very high
b) 7 μm wire dia. provides a localized ion cloud

3) On the other hand, exactly the same recipe would not work with a CsI-based detector. I was not able to demonstrate it to A. Breskin (J.Va'vra et al., NIM A387(1997)154).

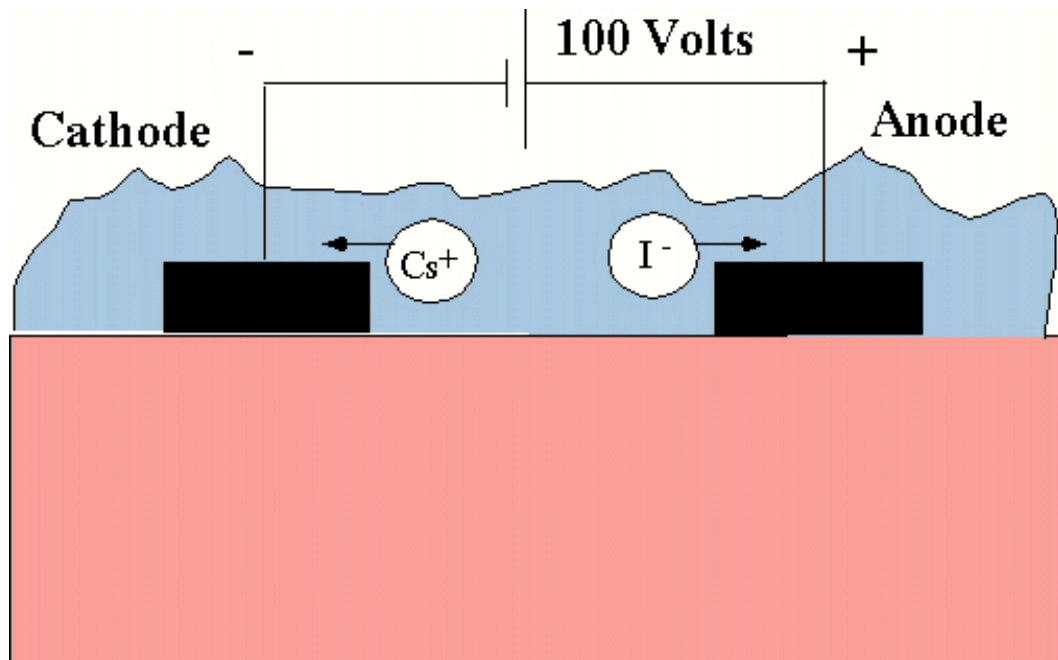


Answer: CsI volume resistivity is much lower:
 $\rho_{\text{CsI film}} \sim 10^{10} \text{ } \Omega \cdot \text{cm}$ (just after evaporation)
 $\rho_{\text{CsI film}} \sim 10^7 \text{ } \Omega \cdot \text{cm}$ (after ~ 10 min in air)

- Possible explanation: the chamber was exposed to air for ~ 10 min to transfer it from the evaporation chamber into the detector setup, and thus CsI resistance was substantially lower. If true, one should make the same test again with the photocathode prepared without exposing to air.

- Electrolytic process in CsI

(J. Va'vra et al., NIM, A387(1997)154; and my talk at DESY Aging Workshop, 2001)



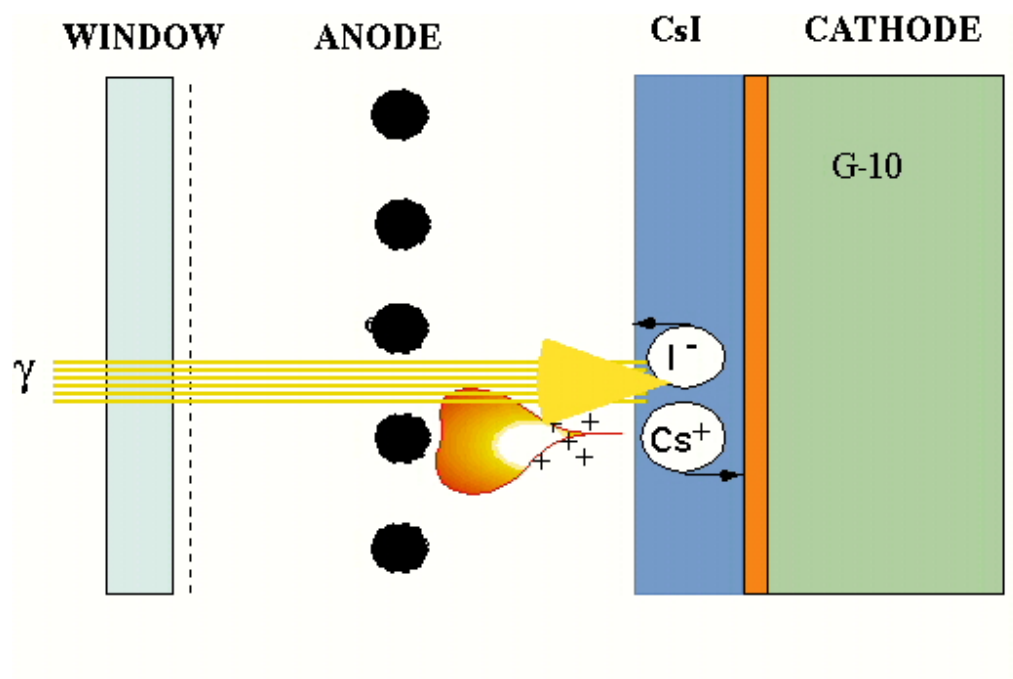
- The current in alkali halides is of an ionic origin, i.e., for example in the CsI, it is carried by the Cs^+ and I^- ions.
- One can clearly observe this effect visually.

- This may be a mechanism to alter the resistance of CsI photocathode, and thus cause the Malter effect.
 - Iodine is very resistive $\rho \sim 1.3 \times 10^9 \Omega \cdot \text{cm}$
 - Cesium is very conductive $\rho \sim 2 \times 10^{-5} \Omega \cdot \text{cm}$

- Electrolytic process in the CsI photocathode

- A high flux of UV photons causes a photocurrent, which brings iodine ions to the cathode surface and the cesium ions in contact with the pad electrodes.

(J. Va'vra et al., NIM, A387(1997)154)



This also will alter the chemistry of the surface and may alter the quantum efficiency and the resistivity of the photocathode. Iodine, which is more resistive, will move towards the surface.

How to prevent the Malter effect ?

- Run as low gas gain as possible ($<2 \times 10^4$).
- Pay attention to the anomalous single electron signal activity.
- Segment the HV as much as possible.
- Monitor currents to a nA sensitivity.
- Develop a “clever” software which can look for:
 - a) the single electron activity on a single wire.
 - b) any remnant activity in the chamber, when the beam goes suddenly away.
 - c) based on such software trip the chamber HV.
- Study additives – see example on next page.

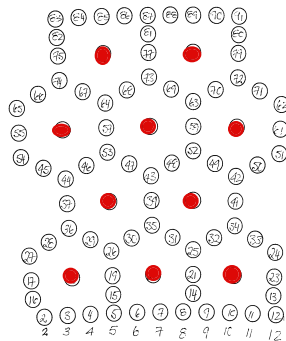
“Good” additive – Oxygen - recovery from the Malter effect deposits

(A. Boyarski's contribution at DESY workshop, 2001)

Gas: 80%He+20%C₄H₁₀+Some additive

Source: 100mC Fe⁵⁵ X-ray source

Test chamber has the BaBar chamber drift cell structure:

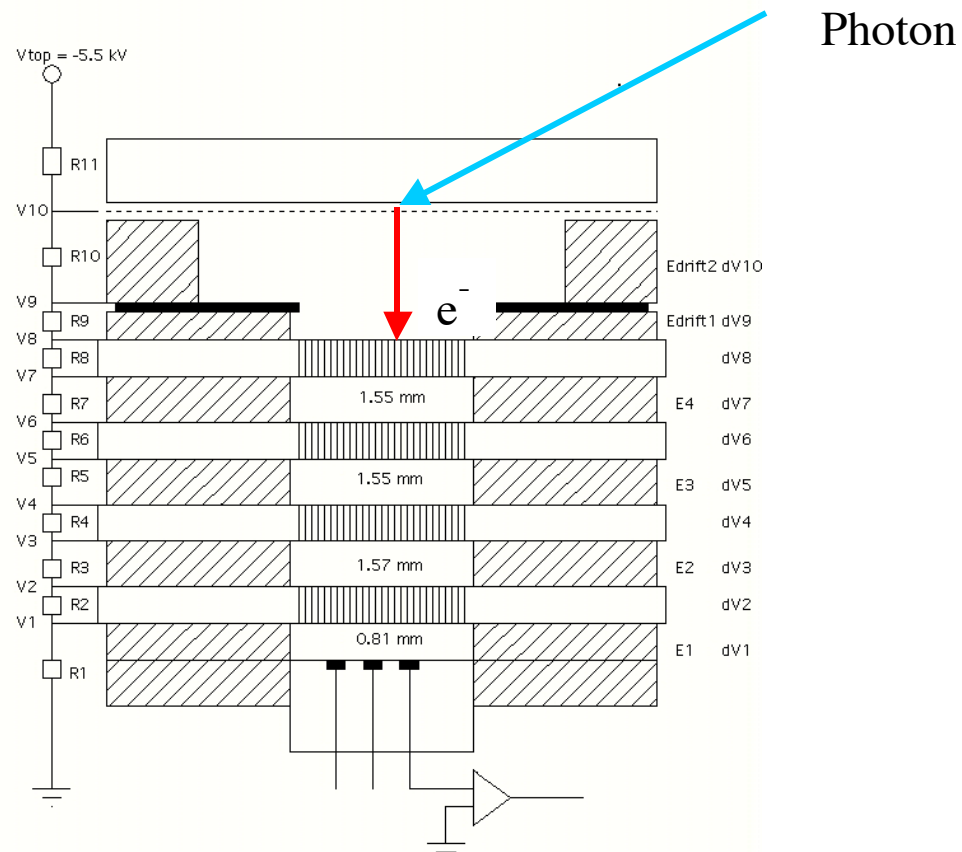


Observations:

1. Start with a damaged chamber – Malter at very low current.
2. Additives such as H₂O or alcohols were shown to stabilize the operation, but not cure it. When the additive were removed, the chamber would suffer from the Malter at very low currents again.
3. However, when 200-1000ppm of O₂ was added, a damaged chamber could be “cured” by allowing a high current operation successively. When the O₂ was removed, the chamber could still operate at high currents, as if it were new (>25nA/cm).
4. Single electron rate is a precursor of the Malter effect.
5. Some evidence of the cathode film heating during the Malter.

Quadruple-GEM Detector design

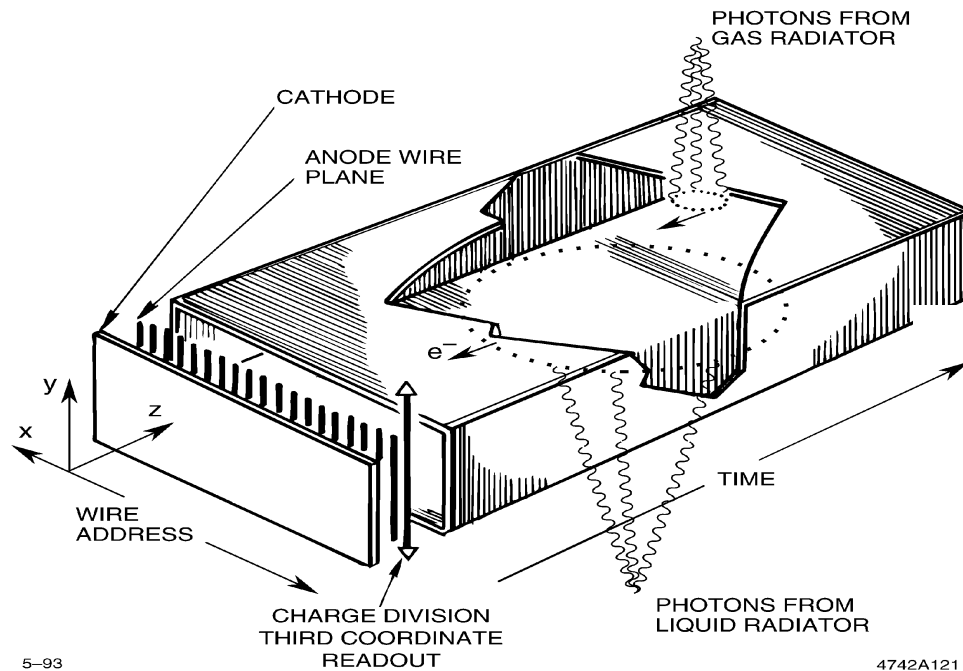
(J. Va'vra and A. Sharma, Vienna Instrumentation conference, February 2001)



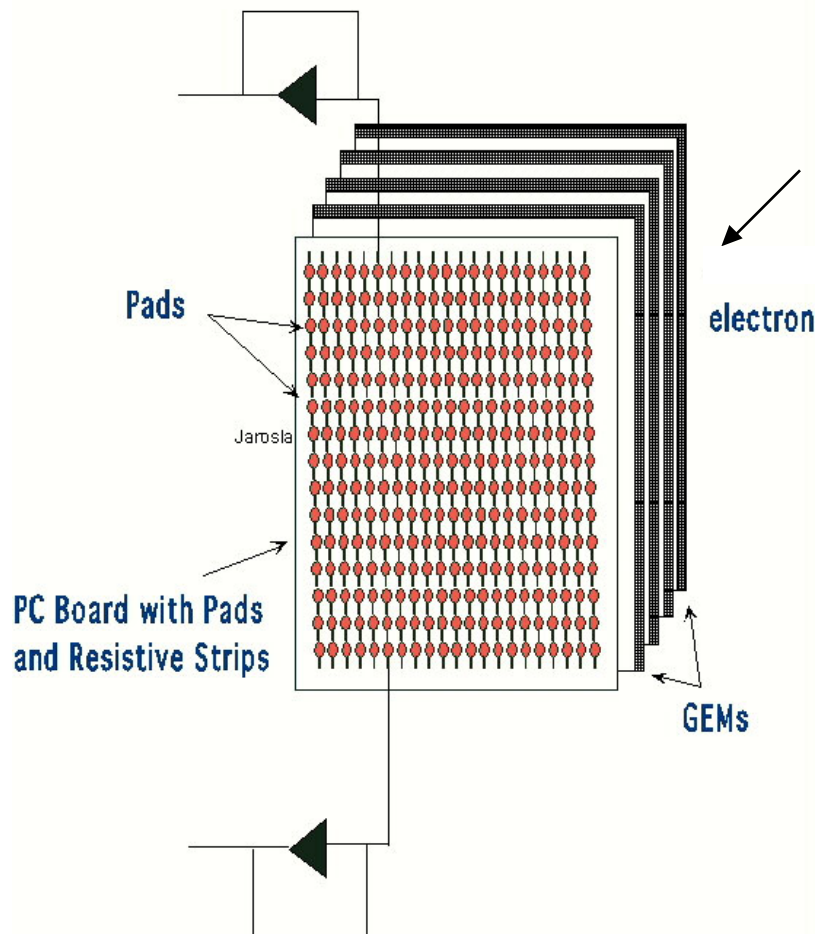
- Four GEM foils are ~ 1.6 mm apart.
- Gap between the last GEM and pads is about ~ 0.8 mm.
- Pad size is 1.25 mm dia., with a pitch of 2.5 mm.
- We use CRID charge amplifier with a gain of ~ 2.7 $\mu\text{V/el.}$, with a ~ 65 ns shaping time constant, 2000 el. noise (high).
- GEMs were made at CERN Surface Treatment Workshop, and provided to us by F. Sauli. They have 120 μm pitch, Kapton hole is 40 μm dia., and copper hole is 80 μm dia., i.e., a conical hole in the Kapton portion of GEM.

Motivation

- 1) In 1998, the SLD was thinking about a final run to accumulate ~ 1 million Z^0 s (this is now unlikely).
- Idea: Replace of the old single electron detectors with a new one, based on a new concept. Re-use old TPCs and the electronics, and use ethane gas as CRID did (a lot of experience with it).

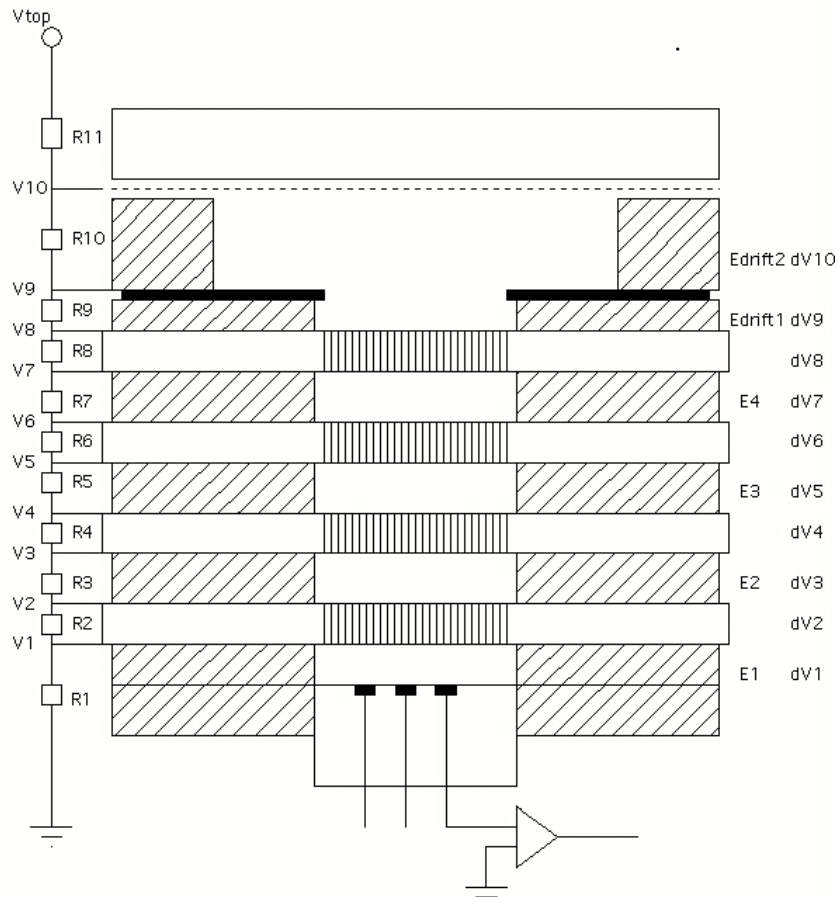


Overall practical concept



- Pads are connected with resistive $\sim 40 \text{ k}\Omega$ strip, which matches the requirement of the CRID charge division CRID electronics.
- The CRID TPC drift field is $\sim 400 \text{ V/cm}$, which allows a good electron transfer efficiency into the GEM.
- The disadvantage of the charge division: higher gain.

J.V., 2.2.12000

Quadruple GEM Detector with PAD readout**Quadruple-GEM resistor chain design for the ethane gas operation:**

The 1-st measurement:

Vtop [V] =	5500
Current [mA] =	0.05965

Pads: 0.052" dia., 0.100" pitch

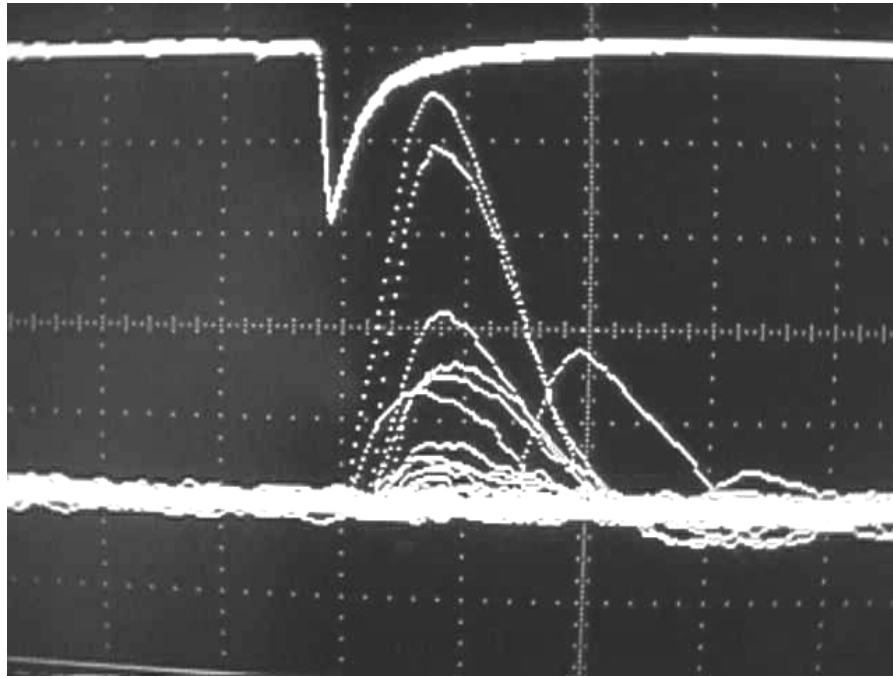
(Note: values of resistors are from the 1-st attempt of 4.5.2000)

Resistors	[Mohms]	Voltages	[V]	dV	[V]	E	[kV/cm]	Width/Thickness [cm]
R1	7	V1	417.5	dV1	417.5	E1	5.137	0.08128
R2	7.29	V2	852.4	dV2	434.8	E-GEM1	83.62	0.0052
R3	9.91	V3	1444	dV3	591.1	E2	3.754	0.15748
R4	8.01	V4	1921	dV4	477.8	E-GEM2	91.88	0.0052
R5	10.02	V5	2519	dV5	597.7	E3	3.858	0.15494
R6	9.03	V6	3058	dV6	538.6	E-GEM3	103.6	0.0052
R7	9.98	V7	3653	dV7	595.3	E4	3.842	0.15494
R8	9.96	V8	4247	dV8	594.1	E-GEM4	114.3	0.0052
R9	0.996	V9	4306	dV9	59.41	Edrift 1	1.063	0.05588
R10	10.04	V10	4905	dV10	598.9	Edrift 2	1.174	0.51
R11	9.97	Vtop	5500					

Total: 92.206

Single electron pulses in ethane

Ethane, $V_{\text{top}} = -5.5\text{kV}$:

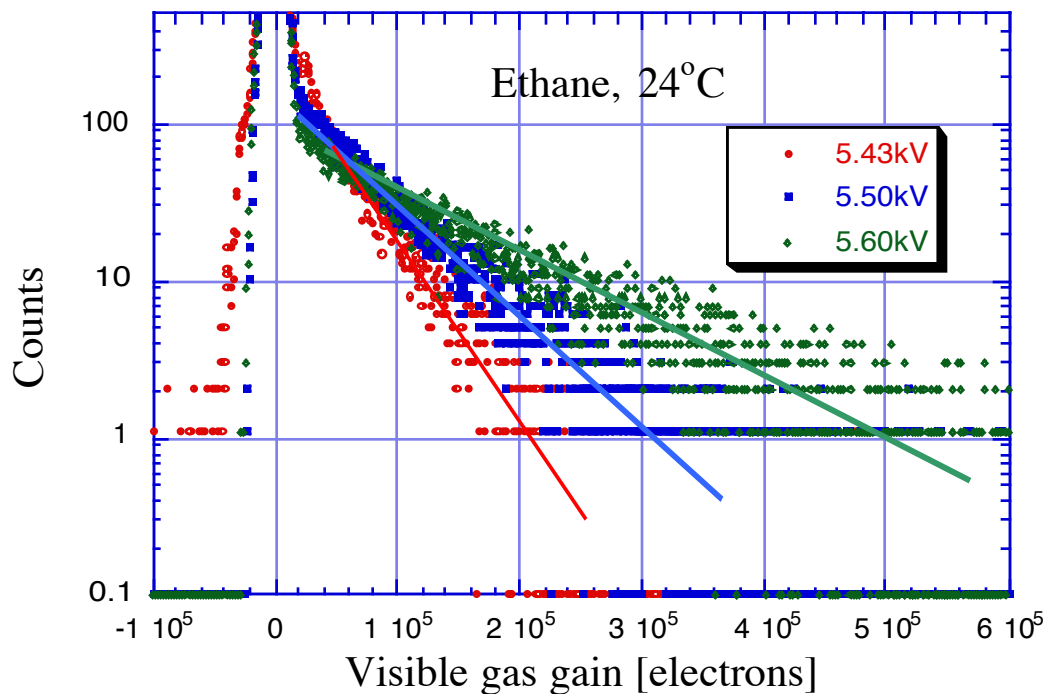


Top trace: 200mV/div, bottom trace: 50mV/div; Time: 200ns/div.

-
- Trigger scope with the signal from the UV photodiode.
 - Single electrons produced off the mesh.

Single electron pulse height spectra

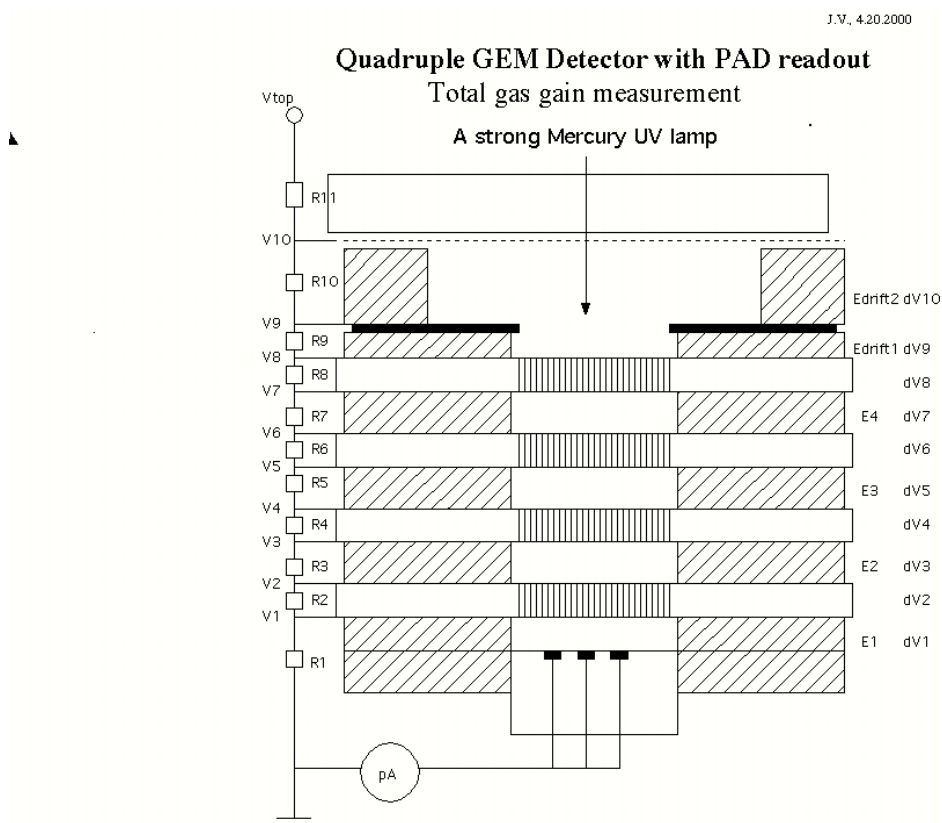
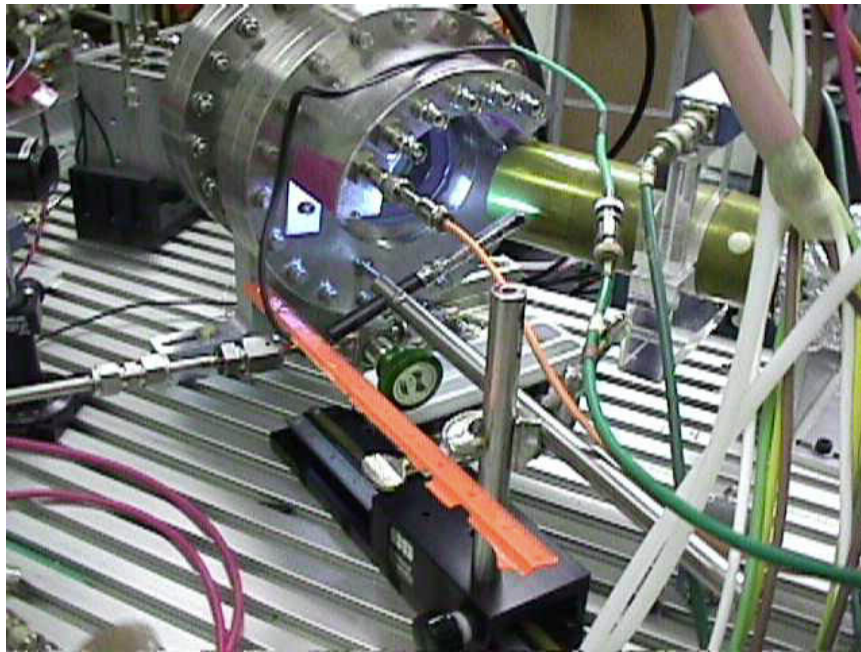
Ethane, vary V_{top} :



- All single electron spectra have an exponential shape.
- No sign of a poor quenching, which would show up as an excessive tail in the single electron spectrum.
- No problem to over-voltage the detector up to ~ 5.9 kV, provided that we are in the single electron mode of operation.

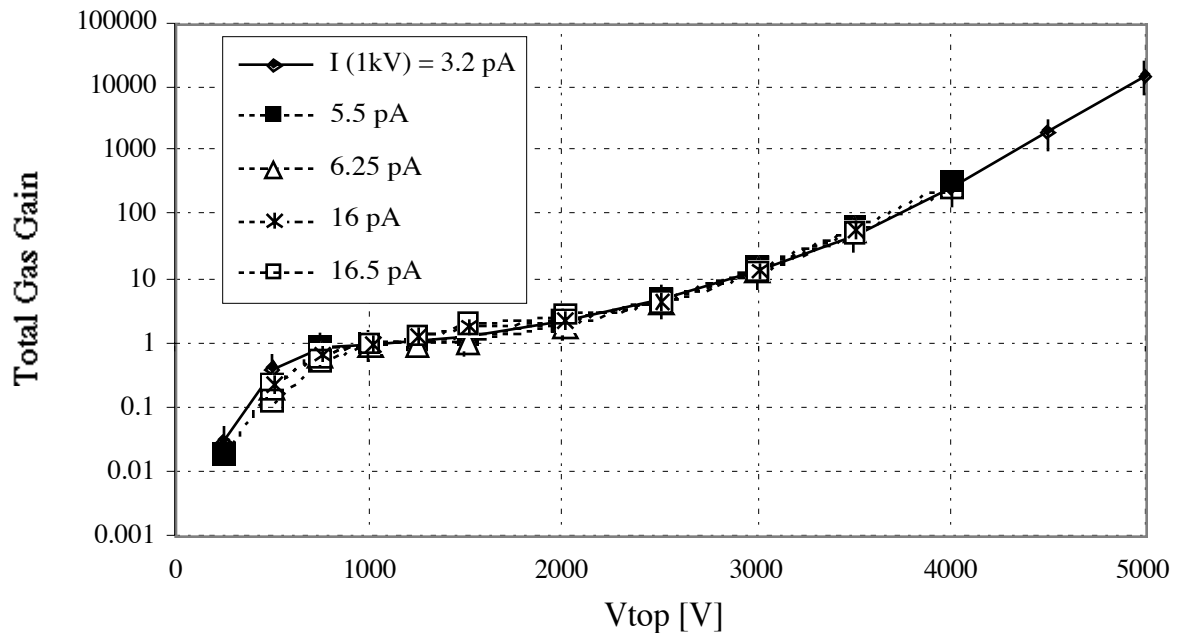
Comment on the shaping time

- This test was assuming that we will use the SLD CRID electronics ($\sigma \sim 2000$ el.), which had the shaping time of 65ns. This choice, plus a choice of using the charge division, forced us to operate at the average visible gain of $\sim 10^5$.
- Similar short shaping time constants apply for experiments at LHC or HERA-b.
- However, given the fact that we are using the pad electronics and not a very high rate, one could use much longer shaping time of $\sim 0.5 \mu\text{s}$, which would allow to reduce the average visible gain of the detector to $\sim 2 \times 10^4$, possibly.
Note: That was the idea of the ALICE CsI detectors, and that is why I was very much surprised that they are apparently running at much larger gain at STAR experiment (according to N. Smirnov).



Charging effects = f(photon flux)

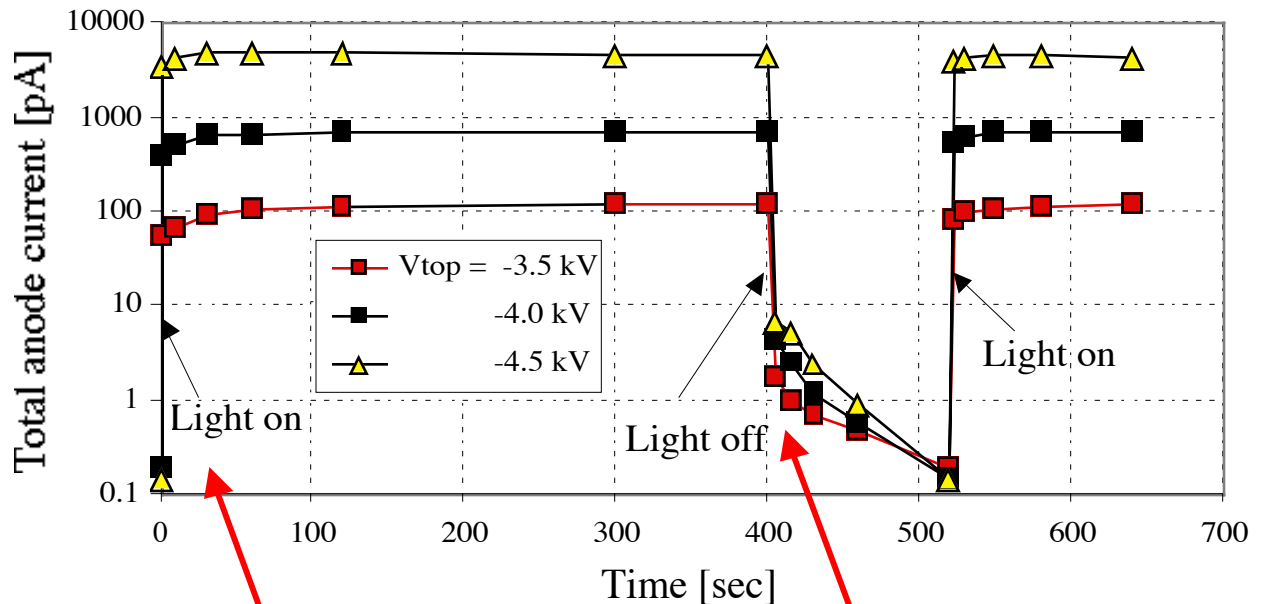
Ethane+TMAE(15°C), humidity ~5ppm:



- If we assume the Q.E. of ~ 0.1 , we are dealing with this range of photon fluxes: $1.5 \times 10^6 - 10^7$ ph./sec/mm².
- Observe no charging effect on the gain up to the total anode current of $I(V_{\text{top}} = -1\text{kV}) = 15\text{-}20$ pA, which corresponds to the anode current density of less than ~ 0.16 pA/mm², or the entrance photoelectron rate up to 10^6 el./sec/mm².
- Results of tests with larger currents are being analyzed.

Charging effects – response to the photon flux bursts (on/off)

Ethane, low photoelectron flux:



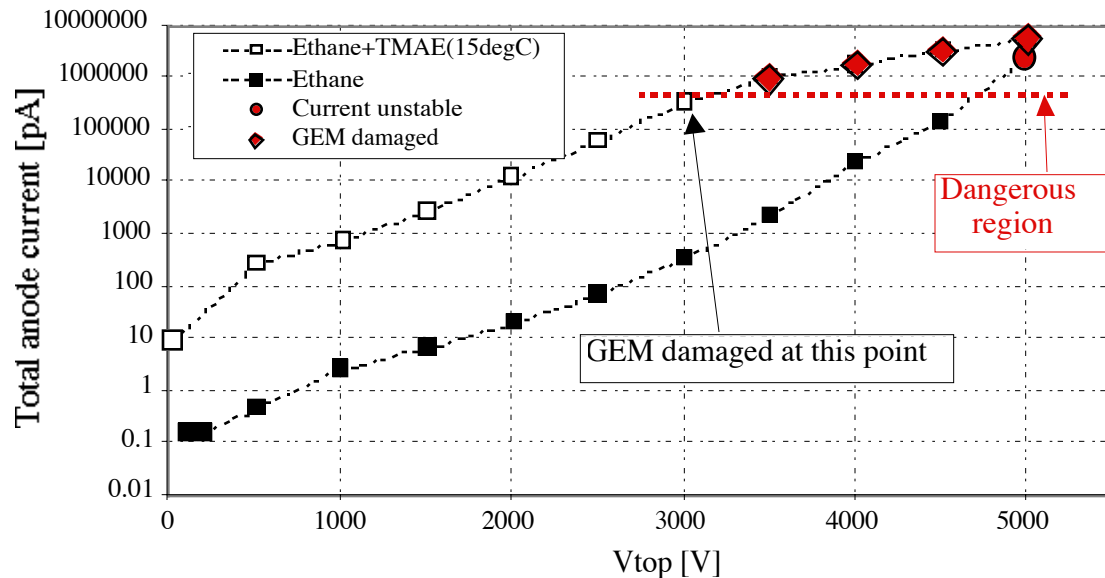
The initial charging current is lower by ~30-40% compared a final current value obtained after 2-3 minutes

The initial remnant current is at a level of ~1% immediately after switching the light off

- Very dry ethane gas in this test. Humidity at a level of ~5ppm.
- UV light from Mercury lamp switched on/off with a shutter.

Damage caused by large currents

Low & high photoelectron rates:



- The damage occurred in ethane+TMAE gas at the total anode current of ~ 360 nA.
- This limit corresponds to the current in the last GEM of $\sim 3 \times 10^8$ electrons/sec/(single hole in the last GEM).
and reduce the total gain to 10^4 , we can improve the background resiliency of this device considerably, indeed.
- It is not clear to me if a similar damage can occur in CsI distributed along the sides of the GEM holes. Needs to be studied.

Conclusion:

Run at as low gas gain as possible, even if you have to compromise physics to some extent.

Make tests at very realistic conditions.

Be afraid, even paranoid, and that gives you a chance to catch bad effects in the early stages when they still do not matter.

Allowing sparking is definitely a bad idea since it can cause changes in the surface resistance, which can cause the Malter effect.